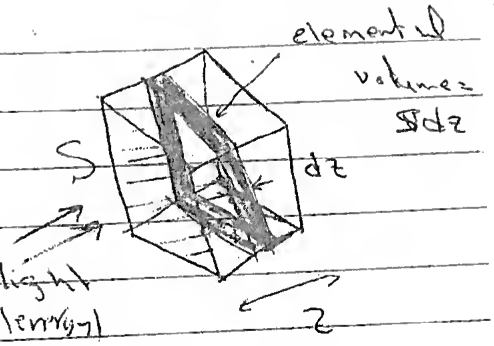
lec. 14

Date:

٣ الأحد ٢١/٦/١٢

cross sectional area

→ propagation direction



gy

Power = $\frac{\text{energy}}{\text{unit time}}$

Irradiance = $\frac{\text{Power}}{\text{unit area}} = I$

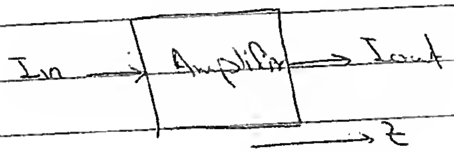
energy density = energy / unit volume

energy

1) Absorption (stimulated)

2) Stimulated Emission

Design amplifier ?



$I_{out} > I_{in}$

Rate of absorption (R_{ab})

$R_{ab} = B_{cr} \times P_\nu \times P_{abs} \times U$

where: $B = \frac{\upsilon^3}{8\pi h Z_r \nu^3}$, υ = speed of wave inside material

ν = frequency of incident wave

R_{ab}: no of absorbed photons / unit volume / unit time.

no. of absorbed photons in volume ($S\,dz$) = $B P_\nu \times P_{abs} \times U \times S\,dz$

energy absorbed in $S\,dz$ = $B P_\nu P_{abs} U\, S\,dz \times h\nu$

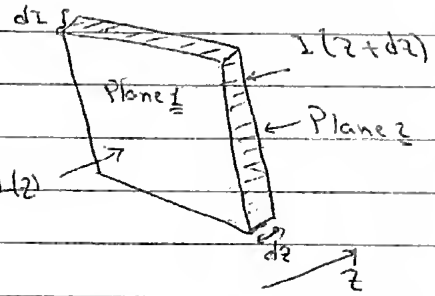
Similarly:-

Energy emitted $= N_2 S t \times S\,dz \times h\nu$

$= B \rho_\nu P_e U S\,dz\, h\nu$

Net energy = emitted − Absorption

$= B \rho_\nu U S\,dz\, h\nu\,(P_e - P_{abs})$ / unit time



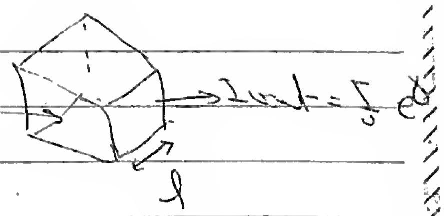
$dI \times S \Rightarrow$ power

$dI \times S = B \rho_\nu U S\,dz\, h\nu\,(P_e - P_{abs})$

$\frac{dI}{dz} = B \rho_\nu U\, h\nu\,(P_e - P_{abs})$ $\qquad U = \frac{I}{v}$

$\frac{dI}{dz} = \underbrace{\boxed{\frac{B \rho_\nu h\nu}{v_{speed}}\,(P_e - P_{abs})}}_{\gamma} I(z)$

$\boxed{\frac{dI}{dz} = \gamma I(z)}$ $\quad \therefore I(z) = I_0 e^{\gamma z}$



γ

+ve	−ve
$I_{out} > I_{in}$	$I_{out} < I_{in}$
Amplifier	Attenuator
Gain = G	loss = G
$P_e > P_{abs}$	$P_e < P_{abs}$

Date

$$\boxed{\gamma = \frac{B\, \rho_\nu\, h\nu}{\nu}\,(P_e - P_{abs})}$$

$$\rho_\nu = \frac{1}{\pi \hbar^2}\,(2m_r)^{3/2}\,(h\nu - E_g)^{1/2} \quad , \quad h\nu > E_g$$

$$B = \frac{\nu^3}{8\pi h \nu^3}$$

[illegible] $\longrightarrow P_e > P_{abs} \longrightarrow$ amplifier

$\downarrow$

two fermi levels E_{fc}, E_{fv}

two fermi functions.

$$P_e = f_c(E_2) \times [1 - f_v(E_1)] = \frac{1}{e^{(E_2 - E_{fc})/KT} + 1} \cdot \frac{e^{(E_1 - E_{fv})/KT}}{e^{(E_1 - E_{fv})/KT} + 1}$$

$$P_{abs} = f_v(E_1) \times [1 - f_c(E_2)] = \frac{1}{e^{(E_1 - E_{fv})/KT} + 1} \cdot \frac{e^{(E_2 - E_{fc})/KT}}{e^{(E_2 - E_{fc})/KT} + 1}$$

$$P_e > P_{abs}$$

$$e^{(E_1 - E_{fv})/KT} > e^{(E_2 - E_{fc})/KT}$$

$$E_1 - E_{fv} > E_2 - E_{fc}$$

$$E_{fc} - E_{fv} > E_2 - E_1$$

$$E_2 - E_1 < E_{fc} - E_{fv}$$

$$\boxed{h\nu < (E_{fc} - E_{fv})}$$

$$E_g < h\nu < E_{fc} - E_{fv}$$

$$\boxed{\frac{E_g}{h} < \nu < \frac{E_{fc} - E_{fv}}{h}} \Longrightarrow \text{Amplification}$$

$$P_e - P_{abs} = f_c(E_2)\times[1-f_v(E_1)] - f_v(E_1)\times[1-f_c(E_2)]$$
$$= f_c(E_2) - f_v(E_1)$$

$$\therefore \gamma = \frac{v^3}{8\pi h \nu^3 \tau} \times \frac{1}{\pi \hbar^2}(2m_r)^{3/2}\,\frac{h\nu}{v}\,(h\nu - E_g)^{1/2}\,[f_c(E_2) - f_v(E_1)]$$

$$\gamma = \frac{v^2 (2m_r)^{3/2}}{2h^2 \tau \nu^2}(h\nu - E_g)^{1/2}\,[f_c(E_2) - f_v(E_1)]$$

ex: at $T = 0°K$

ⓐ at Thermal Equilibrium:

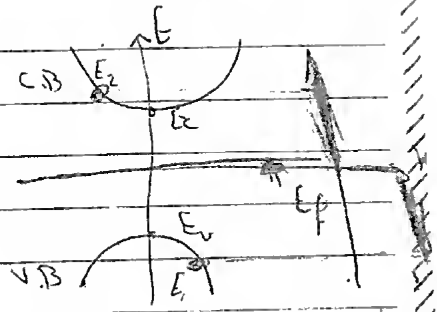
$f(E_2) = 0$

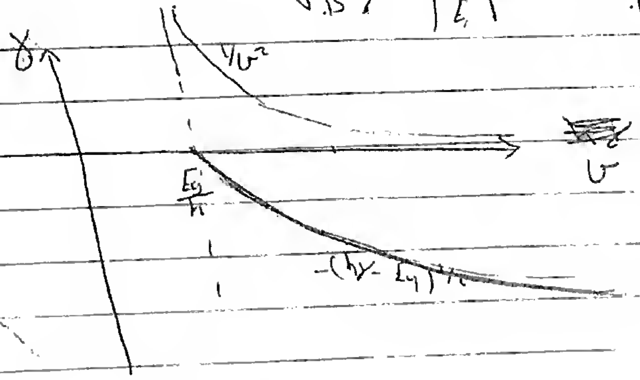
$f(E_1) = 1$

$f(E_2) - f(E_1) = -1$

$\gamma = -ve$

attenuator





ⓑ at Quasi Equilibrium:

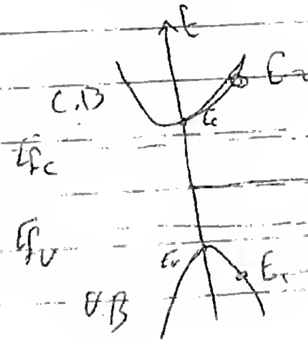
$f(E_2) = 0$

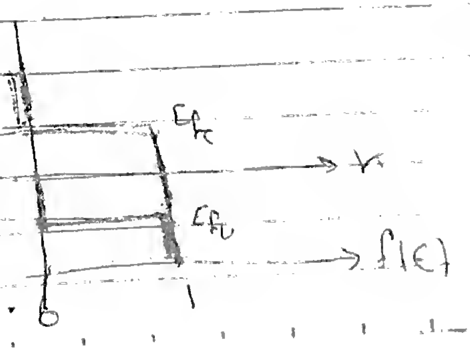
$f(E_1) = 1$

$f(E_2) - f(E_1) = -1$

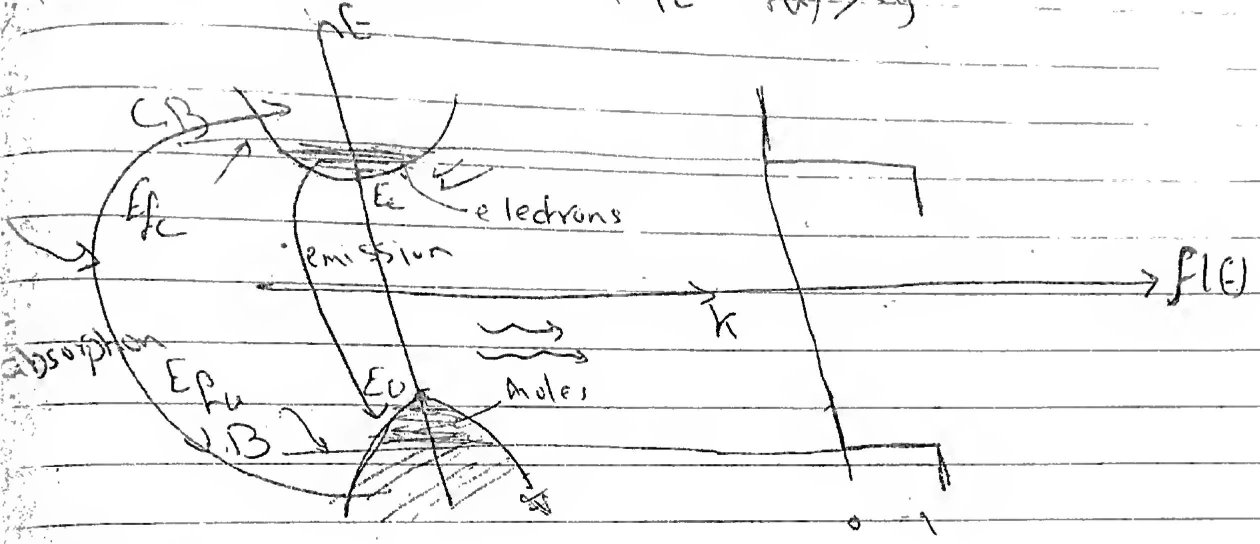
$\gamma = -ve$

attenuator





Quasi equilibrium $(E_{fc}-E_{fv})>E_g$



$f(E_2)=1$

$f(E_1)=0$

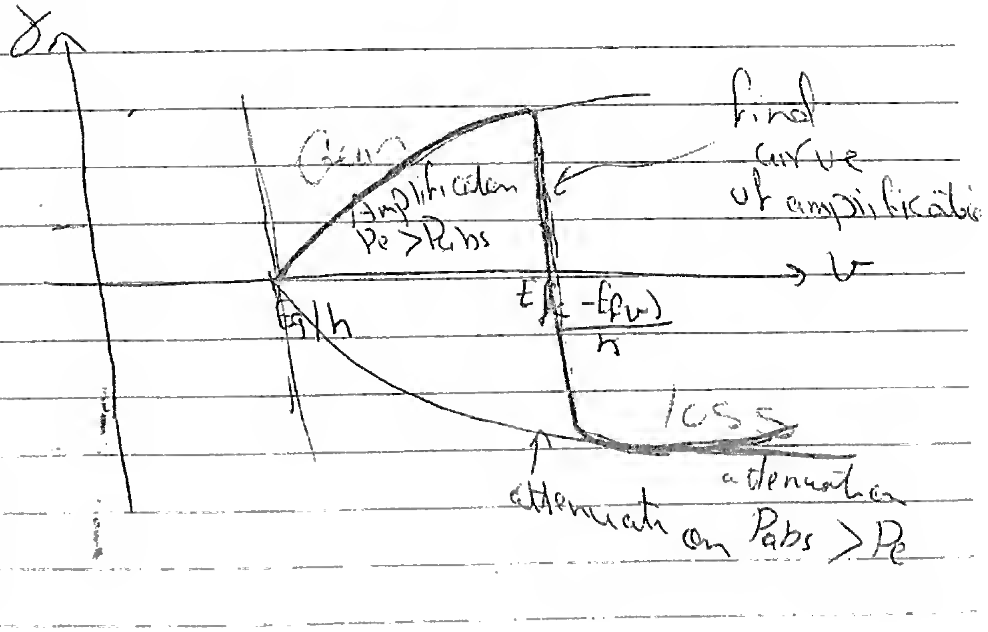
$f_c(E_2)-f_v(E_1)=1$

$\gamma=+ve$

Amplifier

* لو عطيت photon لـ هذه المادة هيحصل emission
اذا كان فرق الطاقة اقل من $E_{fc}-E_{fv}$

* لو عطيت photon لـ هذه المادة هيحصل absorption
اذا كان فرق الطاقة اكبر من $E_{fc}-E_{fv}$



ex:- $E_g = 1eV$ $E_{f_c} - E_{f_v} \cong 1.2 eV$

$$\frac{E_g}{h} = \frac{1 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} \cong 0.25 \times 10^{+15} Hz = 250 T Hz$$

$$\frac{E_{f_c} - E_{f_v}}{h} = \frac{1.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} =$$

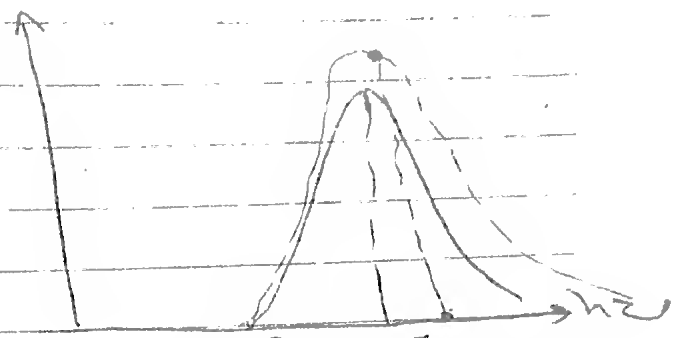
$$BW \cong \frac{0.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$$

GaN $E_g = 3.35\ eV$

$T \uparrow \quad D_0 \uparrow$

$D_0(T) \uparrow$

Band width $\uparrow$



شرط حدوث إشعاع من المادة

١ Semicond Direct mat

٢ Bumbing Forward Bias

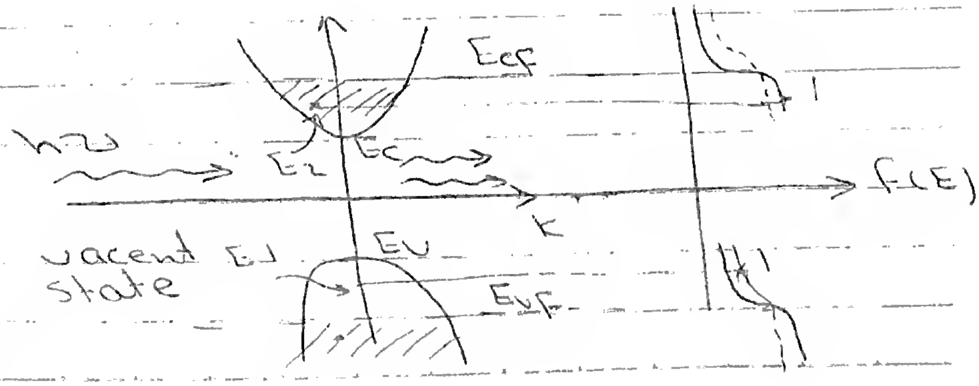
X ناقص معامل الامتصاص

lec (15) دالبال

$$\gamma = \frac{(c/n)^2 (2m_r)^{3/2}}{2\tau_r (h\nu)^2} (h\nu - E_g)^{1/2}$$

$$\times (f_c(E_2) - f_v(E_1))$$

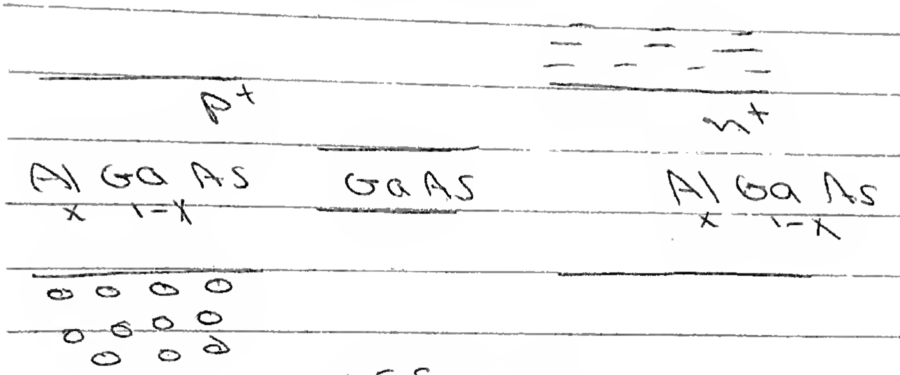
at $T = 0K$ $f_c(E_2) - f_v(E_1) = 1$

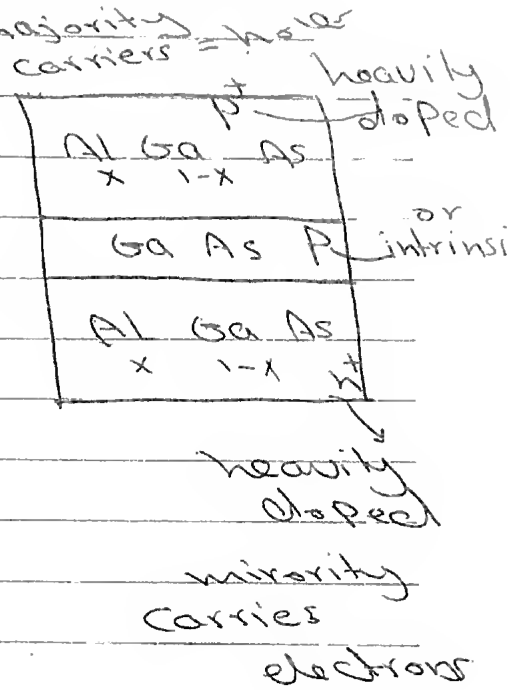


Main structure

double hetrostructure

Band digram





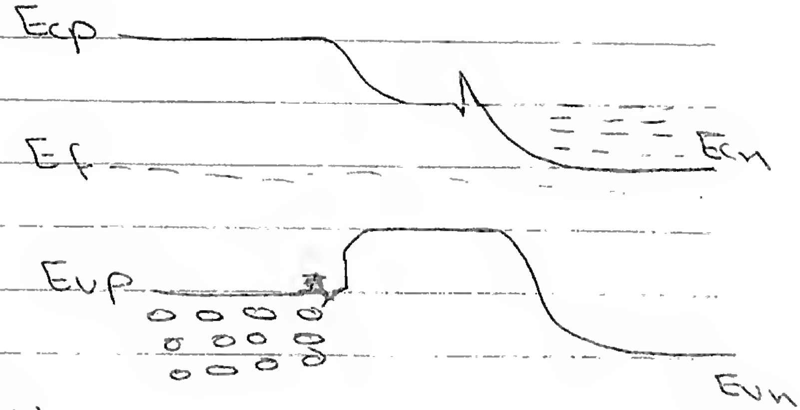
assume

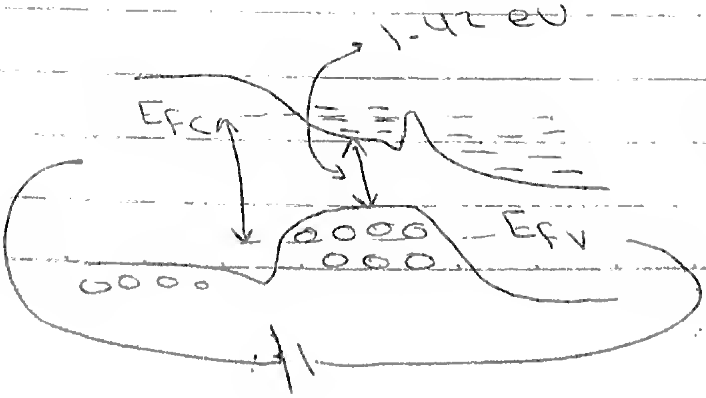
$x = 0.1$

$E_g = 1.5\ eV$

$E_g = 1.42\ eV$

steady state

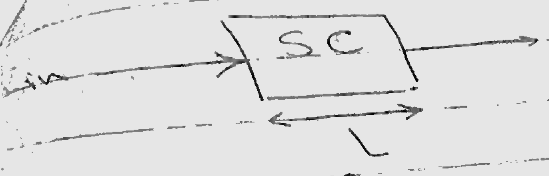




في حالة التوصيل

F.B

Attenuation



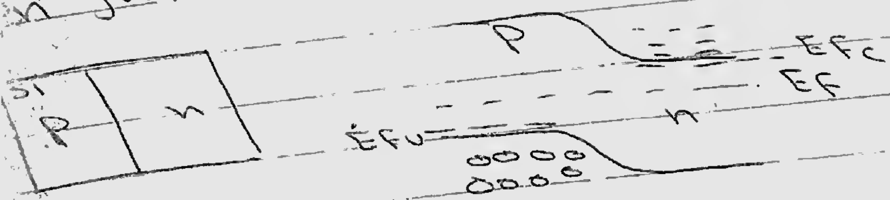
$I_{out} = I_{in}\, e^{\gamma L}$

$\gamma > 0$ — Amp

$\gamma < 0$ — $P_e < P_{abs}$

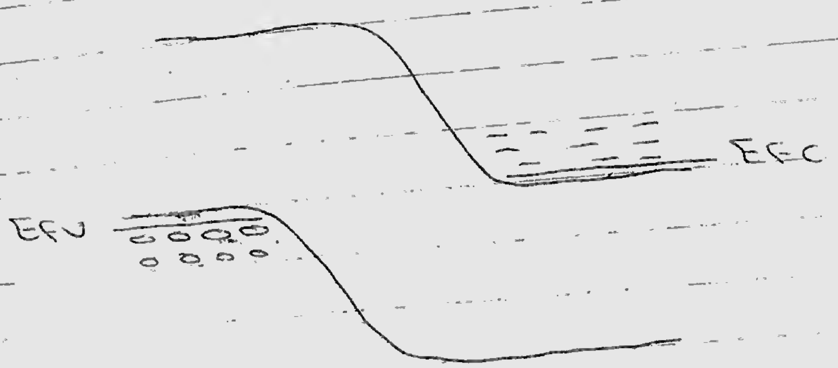
$P_e - P_{abs} = f_c(E_2) - f_v(E_1) < 0$

pn junction



لو وصلت FB --- ↑ c 0000 ↓ [illegible]

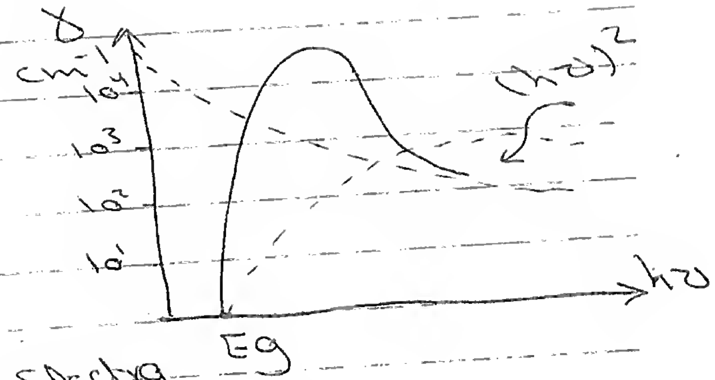
العكس هيوصل R.B



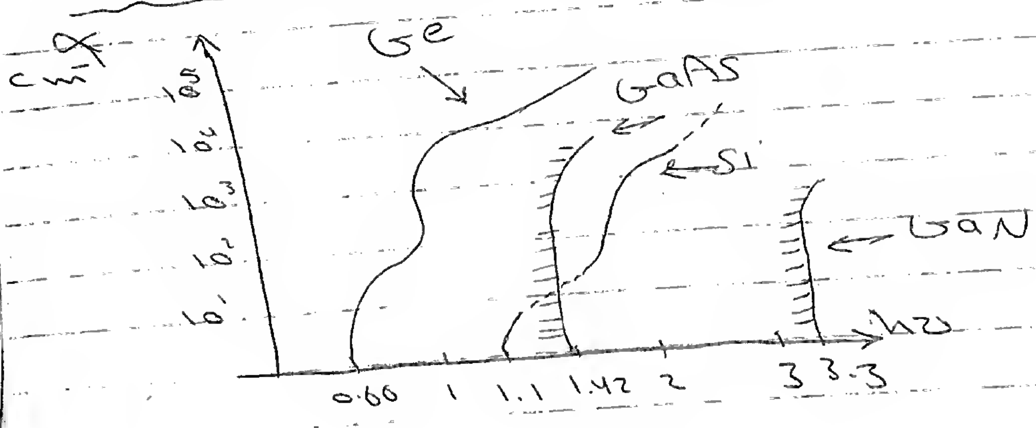
absorp spectrum

$\gamma = -\alpha_{abs}$ للتخلص من العلامة السالبة

$$\alpha_{abs} = \frac{(c/n)^2 (2m_r)^{3/2}}{2\tau_r \; (h\nu)^2} (h\nu - E_g)^{1/2}$$



Typical Absorption spectra



Comments on curve

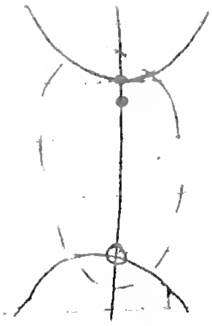
* Any material either Direct or Indirect absorp
* Absorption increases with freq

⇒ curves consider indirect band gap

Eg - Binding energy
(10 mev)

معيار الـ Energy الـ
ضعيفة

attraction
Colomb's force



Excited electron hole
pair

report about ④ NanoStructure mat

lec (16)   دانيال

Photo conductors
Device that its conductivity changes
with the light incidence

Photodiode   Photoresistor   Phototransi   Solar cell

Pn   PIN   APD

General clc's
1- Quantum efficiency η
2- Responsivity R
3- Response time
4- Noise Power

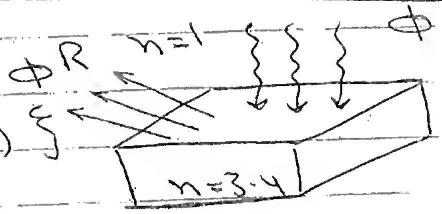
$$\eta = \frac{\text{created carrier flux}}{\text{incident Photon flux}} = \frac{\overset{\text{تيار}}{I_{ph}} / \overset{\text{شحنة}}{e}}{\underset{\text{Power}}{P_{opt}} / (h\nu)}$$

$$\frac{I_{ph}}{P_{opt}} \cdot \frac{h\nu}{e} \rightarrow \frac{h}{e} \cdot \frac{c}{\lambda} = \frac{1.24}{\lambda(\mu m)}$$

$$\frac{I_{ph}}{P_{opt}} \rightarrow R \left(\frac{A}{W}\right)$$

$$\boxed{\eta = R * \frac{1.24}{\lambda(\mu m)} \qquad R = \frac{\eta * \lambda(\mu m)}{1.24}}$$

...gy Absorbed
$(1-R)(1-e^{-\alpha d})\zeta$



$h\nu$

$$I_{in} \longrightarrow \boxed{(1-e^{-\alpha d})} \longrightarrow I_{in}\, e^{-\alpha d}$$

مقدار اللي امتصه ال material

$$\eta = (1-R)(1-e^{-\alpha d})\zeta \qquad 1 > \zeta > 0 \ (\text{Zeta})$$

<u>How to maximize η?</u>

R (reflection) <<<

coating عن طريق ال

Indium tin oxide Int (Si)

...kness of coating mat & function (incident wavelength)

Designed PD is tened at specific wavelength

② $e^{-\alpha d} <<<$

$\alpha d >>$

d (thickness of PD) ↑↑ α ↑↑ (atten const)

يعني لو صناع ددل اختار $\alpha <<<$ بالعكس

③ { material ~~functions~~ fabrication

⇓

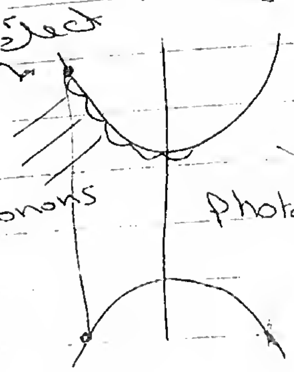
⇐ less danglingbonds ⇐ less defects

less trap states ⟹ high performance

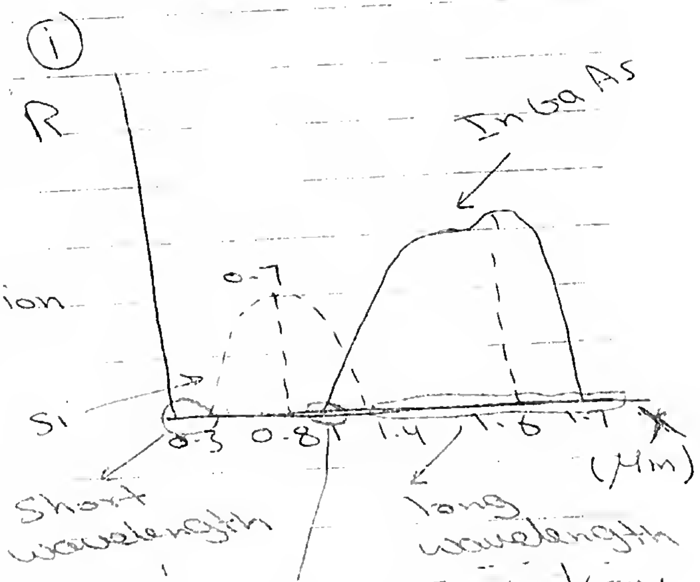
② R

كنت عوض طاقة الـ

جدا يولدى الـ



①



thermilization

وهنا لو في الصرحه بين الـ

R curve , abs curve

1100 nm أكترمن

كدا لا م

min Eg ≡ MAX λ

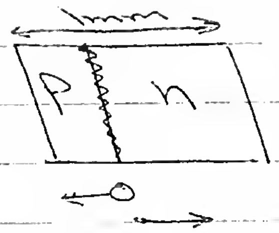
(3)

	μ_e	μ_h
InGaAs	14000	400

* ال e هيمشي مسافات كبيرة وال h هيمشي
مسافات صغيرة لأن ال $\mu_e > \mu_h$

To min time response

① dimension of n & p layers in PD should be adjusted as shown in below to achieve compromise speed for ie, ih



② Choose material with high mobility

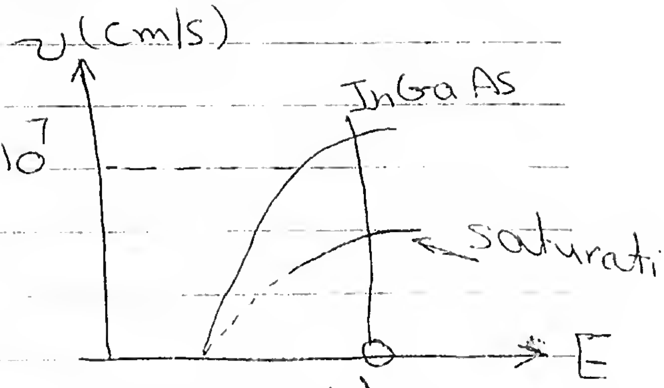
ex):

$$t_s = \frac{1mm}{v_e} \qquad v_e = 10^7 \ cm/s$$

$$t_s \simeq 10^{-8} \ s \qquad \mu \uparrow \qquad t_s \downarrow$$

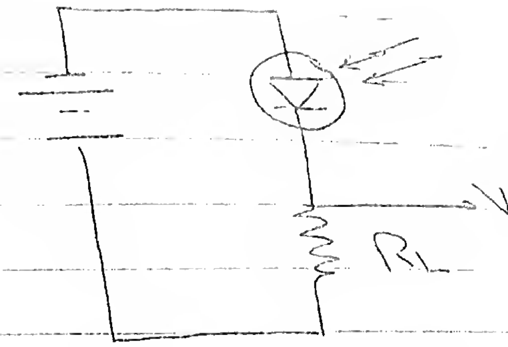
③ Apply E to help electrons & holes to move fast

للإشتغال عند E
يعمل saturation



② Recombination time in circuit

response $\uparrow$ recom t $\downarrow$ $R_L, C \downarrow$

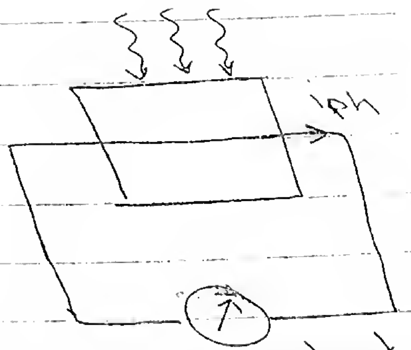


Give reason to use InGaAs

① R curve المنحنى المناسب

② high speed → low time response

4) Noise power



dark circuit generated reverse circuit without incident light

	dark current	~~generated~~
Si ~	1 nA	شائعة في الاستخدام
InGaAs ~	10 nA	Sensing الـ
Ge ~	100 nA	لا يستخدم كثير لأنه
		يؤدي إلى noise power عالية

Common PD Design is PIN

P-type (+ve)

intrinsic mat

n-type (-ve)